

## Dry-Matter Production, Allocation and Nutritive Value of Forage Chicory Cultivars as a Function of Nitrogen

D. P. Belesky, J. M. Ruckle, and W. M. Clapham

Authors' address: Dr D. P. Belesky (corresponding author; e-mail: david.belesky@ars.usda.gov), Ms J. M. Ruckle and Dr W. M. Clapham, United States Department of Agriculture – Agricultural Research Service, Appalachian Farming Systems Research Center, 1224 Airport Road, Beaver, WV 25813-9423, USA

With 6 figures and 7 tables

Received May 12, 2003; accepted July 25, 2003

### Abstract

Forage chicory cultivars vary in origin and morphology and may respond differently to nutrient inputs because of photosynthate allocation and resource acquisition. Understanding nitrogen (N) influences on chicory seedling development and allocation of photosynthates among plant parts is important in terms of stand establishment, plant persistence, herbage production and nutritive value. We conducted experiments in the glasshouse to determine if amount (0, 50 and 100 mg N kg<sup>-1</sup> soil) and source (ammonium nitrate or urea) of exogenous N influenced leaf dry-matter (DM) production, N nitrate (NO<sub>3</sub>) and total non-structural carbohydrate (TNC) allocation among roots and shoots in the chicory cultivars Forage Feast, Lacerta or Grasslands Puna. Herbage DM productivity and the ratio of energy (TNC): protein varied among cultivars because of differential photosynthate allocation between shoots and roots, and occurred later in the growth interval when N was applied. Forage Feast, compared with the other cultivars, produced the largest roots and greatest herbage DM without added N. Leaf appearance rate in Lacerta and Grasslands Puna increased with increasing N. Instantaneous growth rates of Grasslands Puna and Lacerta at 100 N were three times that of 0 N plants. Nitrate concentrations were very high in young seedlings of all three cultivars before applying N. The findings help define application practices for these cultivars and N management practices for optimal leaf production in establishing forage chicory plants.

**Key words:** *Cichorium intybus* L. — energy : protein ratio — growth rates — leaf appearance — nitrogen productivity

### Introduction

Chicory (*Cichorium intybus* L.) can supplement mid- and late-season forage production in eastern North America (Jung et al. 1996, Belesky et al.

1999, Kunelius and MacRae 1999) and most likely other regions with similar growing conditions. Chicory grown for forage responds to N fertilizer, with greater herbage mass and larger leaves resulting from greater rates of N (Belesky and Ruckle 2000). Understanding N influences on chicory is important from the standpoint of stand establishment, plant persistence, herbage production and nutritive value. Insufficient N often stimulates root production at the expense of herbage (Ameziane et al. 1995), influencing shoot-to-root ratio (Jarvis and MacDuff 1989) and overall productivity. Defoliation disturbs the shoot-to-root relationship and may cause accumulation of NO<sub>3</sub> (Vuylsteker et al. 1997), and thus influences productivity and nutritive value.

Management practices, such as clipping or periodic grazing, developed in New Zealand were designed to suppress stem development and maintain a leafy, vegetative plant preferred by grazing livestock (Li et al. 1994). Increased productivity of N-fertilized plants may, in part, be a product of delayed maturity (culm expression) that occurs when N is applied to leafy crop plants (Locascio et al. 1984). Clapham et al. (2001) found established plants of forage chicory would respond as reproductive or vegetative plants for a particular growing season.

Extensive literature supports the value of Grasslands Puna for forage production, but very little is known about the development and production of Lacerta or Forage Feast. Early seedling development influences establishment success (Sanderson and Elwinger 2000) and ultimately sward persistence, but details on the influence of N application

on development of forage chicory seedlings, while important are limited (Collins and McCoy 1997, Alemseged et al. 2003). Seedlings of forage chicory cultivars such as Grasslands Puna, Forage Feast and Lacerta appear to differ in leaf number and shoot-to-root allocation patterns when no fertilizer N is applied (Sanderson and Elwinger 2000). Alemseged et al. (2003) suggested that no N was needed at the time of sowing sward mixtures containing chicory and legumes in spring, and that N application should be delayed as long as possible to minimize competition from weeds.

Management practices and growing conditions that influence production and maintenance of leaves in chicory are not clearly understood in terms of N fertilization. Santamaria et al. (1998) noted that growth of chicory cultivars developed for human table use was not influenced by N source, although  $\text{NO}_3$  was the preferred form of N for uptake. We observed morphological differences among cultivars available for forage production with Forage Feast characterized by robust taproot, Lacerta by large leaves, and that Grasslands Puna was intermediate in terms of taproot and leaf size (R. W. Zobel, unpublished data). Wild and domestic grazers discriminated amongst chicory cultivars with Forage Feast preferred less than either Lacerta or Grasslands Puna, and chemical composition of chicory contributed to selectivity (Foster et al. 2001, 2002).

Our objective was to determine if N influenced dry-matter (DM) productivity and DM allocation among plant parts of chicory cultivars. We also sought to determine if amount and form of exogenous N influenced DM productivity, N and  $\text{NO}_3$  concentration, leaf N yield, and energy (as total non-structural carbohydrate; TNC) : protein in leaves of defoliated seedling plants of forage chicory. The findings will help define management practices for optimal forage production while maintaining satisfactory herbage nutritive value as a function of N inputs.

## Materials and Methods

### Growing conditions and treatments

Seed from three chicory cultivars, 'Forage Feast', 'INIA Le Lacerta' and 'Grasslands Puna', specifically developed for forage applications, were sown into 3500 cm<sup>3</sup> volume pots containing 400 g (dry) Professional PRO-MIX<sup>1</sup> growth

medium (Premier Horticulture, Inc. Red Hill, PA). The rooting medium contained 73 mg N, 69 mg P and 245 mg K kg<sup>-1</sup> potting mix. Five replications of five treatments consisting of a control (no exogenous N, 0N) and a single application of urea or  $\text{NH}_4\text{NO}_3$  at 50 mg N kg<sup>-1</sup> (50 N) and 100 mg N kg<sup>-1</sup> (100 N) were established. Application of each N solution was made to damp soil to minimize volatilization loss from urea. Five additional pots of each cultivar were sown providing baseline material sampled at the time of treatment application. Plants were grown in the glasshouse for 3 weeks, at which time seedlings were thinned to nine plants in each pot. Plants were grown at an average day/night temperature of 25/18 °C and ambient summer humidity and light conditions at the location. Pots were placed in trays and watered as needed by subirrigation to minimize water stress or disturbance of plants by surface watering.

### Sample collection and chemical analysis

Plants were clipped to a 10-cm residual plant height at 4 weeks of growth and subsequent harvests made from the same plants clipped repeatedly at 3-week intervals for a total of four harvests (28, 49, 71 and 92 days after planting). The final harvest (day 92) included collecting the 10-cm residual plant leaf stratum, root and all herbage above the residual section of the plant. Freeze-dried tissue was weighed for DM determination and ground in a cyclone mill (Udy Corporation, Fort Collins, CO) to pass a 0.5-mm screen prior to chemical analysis.

Nitrogen was determined by combustion of dry plant tissue on the Carlo Erba EA 1108 CHNSO analyzer (Fisons Instruments, Beverly, MA). Protein was expressed as N concentration multiplied by 6.25. Nitrates were determined by ion-selective electrode (Consalter et al. 1992). TNCs were determined by a modification (Denison et al. 1990) of the Smith (1981) method using an Alpchem RFA 300 autoanalyzer (Astoria-Pacific, Intl. Clackamas, OR).

### Calculations and statistical analysis

Pots were arranged in a completely randomized design and were re-randomized each week to minimize localized effects in the glasshouse. Data for cumulative DM yield, relative DM allocation, shoot : root (s : r), cumulative leaf N yield, whole plant N-use efficiency (NUE), tissue  $\text{NO}_3$  and energy (TNC) : protein were analysed to determine the effects of N source and rate, cultivar, harvest date and the interactions of N source and rate, cultivar and harvest date using PROC-MIXED procedure of SAS (Littell et al. 1996). Single-degree-of-freedom contrasts were used to compare the fixed effects of N source and rate, by cultivar. Denominator degrees of freedom were calculated using the Satterthwaite option of MIXED analysis to determine appropriate degrees of freedom to test fixed effects and interactions of fixed effects with replicate treated as a random variable. Treatment effects and regression trends presented are significant at  $P \leq 0.05$ ; exceptions are noted with P specified.

<sup>1</sup>Trade names are for the convenience of the reader and do not imply endorsement by USDA.

Cumulative DM yield and N yield data (four harvests of foliar material) were analysed by multiple nonlinear regression (PROC NLIN) procedures (Latour and Thompson 1997), where the first derivatives of b0, b1 and b2 are derived and fit to the Gompertz growth model:

$$\text{Yield (DM or N)} = b_0 \times \exp[-b_1 \times \exp(-b_2 \times t)], \quad (1)$$

where t is day after planting. Instantaneous growth rate (IGR) and N accumulation (INA), were computed by the following model (Draper and Smith 1981):

$$\text{IGR} = b_2 \times \text{herbage DM accumulation} \times \log \frac{b_0}{\text{herbage DM accumulation}}, \quad (2)$$

$$\text{INA} = b_2 \times \text{herbage N yield} \times \log \frac{b_0}{\text{herbage N yield}}, \quad (3)$$

where b0 and b2 are regression parameters from equation (1).

Instantaneous accumulation is based on calculations that convert herbage N concentration (%) to g kg<sup>-1</sup> to comply with nonlinear regression analysis protocol. Energy : protein ratio was calculated as the ratio of TNC g 100 kg<sup>-1</sup> : (N g 100 kg<sup>-1</sup> × 6.25). Nitrogen use efficiency (NUE) was calculated as the product of N productivity (g DM whole plant g<sup>-1</sup> N day<sup>-1</sup>) and mean resident time (63 days) that represents the interval between N application and the last harvest (Aerts 1989).

## Results and Discussion

### Dry-matter allocation

The relative allocation of DM among plant parts at the end of the experiment was influenced by N rate and source, and cultivar but not their interaction (Table 1). Leaf accounted for about 58 % of the total DM of Forage Feast, 71 % of Grasslands Puna and 74 % of Lacerta, 92 days after emergence (Table 2). Leaf mass increased, in general, as a fraction of total DM with increasing N, irrespective of N source or cultivar, and corresponds with findings reported by Richard-Molard et al. (1999) for uncut chicory plants. Root mass was greater in Forage Feast than either Grasslands Puna or Lacerta. Residual leaf mass declined with increasing N, regardless of N source (Table 2). Urea compared with 0 N had minimal influence on leaf mass, root and s : r ratio (Table 3). The s : r ratio of Forage Feast was not influenced by N source or amount, but was for Lacerta and Grasslands Puna (Table 3).

Preferential allocation of resources to taproot in Forage Feast was slightly greater than allocation to root in Grasslands Puna and Lacerta that tended towards leaf production as seedling plants. The

Table 1: Analysis of variance for the influence of N rate and source (N), cultivar (C), harvest (H) and the interactions on cumulative dry-matter (DM) yield, relative DM allocation among plant parts, shoot : root (s : r), cumulative leaf N yield, whole plant N use efficiency (NUE), NO<sub>3</sub> and energy (TNC) : protein ratio of forage chicory

	Cumulative DM yield	Relative DM allocation			Cumulative leaf N yield	Whole plant NUE	Leaf NO <sub>3</sub>	Energy : protein	s : r
		Leaf	Residue	Root					
N	49.84***	16.35***	21.96***	6.35***	52.41***	111.34***	65.44***	5.08***	8.63***
C	0.05†	115.91***	111.27***	41.08***	42.42***	47.28***	61.33***	64.73***	13.23***
H	395.49***	—	—	—	447.19***	—	1016.72***	111.78***	—
N × C	4.83***	1.52†	1.95†	1.23†	3.34**	6.82***	35.33***	1.74†	0.97†
N × H	9.85***	—	—	—	18.19***	—	3.42***	4.27***	—
C × H	1.88†	—	—	—	23.12***	—	40.55***	10.24***	—
N × C × H	0.68†	—	—	—	2.63***	—	4.74***	1.44†	—

†, not significant; \*\*P < 0.01, \*\*\*P < 0.001.

Table 2: Dry-matter (DM) allocation of cumulative leaf (all harvests), residual plant leaf (residue, soil surface to 10 cm) and root DM (values are mean  $\pm$  S.E. of the mean) expressed as a fraction of total plant mass ( $\text{g } 100 \text{ g}^{-1}$ ) for Forage Feast, Lacerta and Grasslands Puna, N rate (0, 50 or 100  $\text{mg N kg}^{-1}$  soil) and source (ammonium nitrate, AN or urea, UN) at the final harvest

	Forage Feast			Lacerta			Grasslands Puna		
	Leaf	Root	Residue	Leaf	Root	Residue	Leaf	Root	Residue
0 N	53 $\pm$ 2.3	11 $\pm$ 1.1	36 $\pm$ 1.6	70 $\pm$ 1.0	8 $\pm$ 0.4	22 $\pm$ 0.8	62 $\pm$ 1.3	9 $\pm$ 0.4	29 $\pm$ 1.0
50 AN	56 $\pm$ 1.2	9 $\pm$ 0.5	35 $\pm$ 0.9	75 $\pm$ 1.2	7 $\pm$ 0.4	18 $\pm$ 1.1	72 $\pm$ 0.9	6 $\pm$ 0.2	22 $\pm$ 1.0
50 UN	59 $\pm$ 0.2	9 $\pm$ 0.4	32 $\pm$ 0.5	73 $\pm$ 0.7	6 $\pm$ 0.3	21 $\pm$ 0.7	70 $\pm$ 1.0	8 $\pm$ 0.4	22 $\pm$ 1.0
100 AN	63 $\pm$ 2.9	11 $\pm$ 0.6	26 $\pm$ 2.8	76 $\pm$ 0.9	7 $\pm$ 0.4	17 $\pm$ 0.8	78 $\pm$ 4.4	7 $\pm$ 1.4	15 $\pm$ 3.2
100 UN	61 $\pm$ 1.6	11 $\pm$ 0.6	28 $\pm$ 1.3	77 $\pm$ 0.7	7 $\pm$ 0.2	16 $\pm$ 0.7	74 $\pm$ 0.4	7 $\pm$ 0.3	19 $\pm$ 0.3

Table 3: Selected single-degree-of-freedom comparisons to illustrate the influence of N rate (0, 50 or 100  $\text{mg N kg}^{-1}$  soil) and source (ammonium nitrate, AN or urea, UN) on leaf, root, residual plant leaf (residue) DM and shoot : root (s : r) ratio for Forage Feast, Lacerta and Grasslands Puna chicory

Comparison	Forage Feast				Lacerta				Grasslands Puna			
	Leaf	Root	Residue	s : r	Leaf	Root	Residue	s : r	Leaf	Root	Residue	s : r
0 N vs. 50 AN	ns†	*	*	ns	ns	*	ns	ns	ns	ns	*	ns
0 N vs. 50 UN	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	ns
0 N vs. 100 AN	ns	ns	ns	ns	**	**	**	**	*	**	*	**
0 N vs. 100 UN	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns
100 AN vs. 100 UN	*	ns	**	ns	**	*	**	**	**	*	**	**

†ns, not significant; Significant at \*P < 0.05 and \*\*P < 0.01.

proportion of total mass occurring as root changed with time (data not shown), suggesting that chicory seedlings established roots quickly, and then allocated resources to either above- or below-ground structures depending on N nutrition and the growth strategy of the particular cultivar. Forage Feast was the exception and had about 40 % more root mass and a greater proportion of total mass allocated to root at the end of the experiment than either Lacerta or Grasslands Puna. The strategy of early and rapid root development could, in part, contribute to some of the water stress tolerance of chicory because of a root system capable of exploiting a relatively large soil volume (R. W. Zobel, unpublished data).

### Cumulative DM yield

Cumulative DM yields of Grasslands Puna and Lacerta were similar at 0 N (Fig. 1). Forage Feast produced twice the DM of Grasslands Puna or Lacerta with 0 exogenous N, suggesting that Forage Feast would be a cultivar suited to extensive or low-input situations. Interactions of cultivar with N rate and source and cultivar with harvest date influenced DM production (Table 1). Appli-

cation of 50 N, irrespective of source, appeared to be insufficient to influence chicory DM, with 100 N as  $\text{NH}_4\text{NO}_3$  having the greatest influence on DM of any component of Lacerta or Grasslands Puna (Table 3). Herbage DM was two- to three-fold greater in Grasslands Puna and Forage Feast at 100 N as  $\text{NH}_4\text{NO}_3$ , compared with 0 N. Lacerta DM yield increased with N application irrespective of N source. Urea applied at the 100 N rate caused some leaf scorch that slowed growth. Symptoms disappeared 7–10 days after first appearance.

### Leaf appearance

Harvestable DM of forage chicory depends on leaf appearance and expression. Leaf appearance is less in vegetative chicory plants than in reproductive plants; however, vegetative plants continued to form new leaves throughout the summer while reproductive plants did not and basal leaves senesced (Clapham et al. 2001). Shifting to a population dominated by vegetative plants could improve production and quality of herbage after the early flush of growth common in cool-temperate pastures.

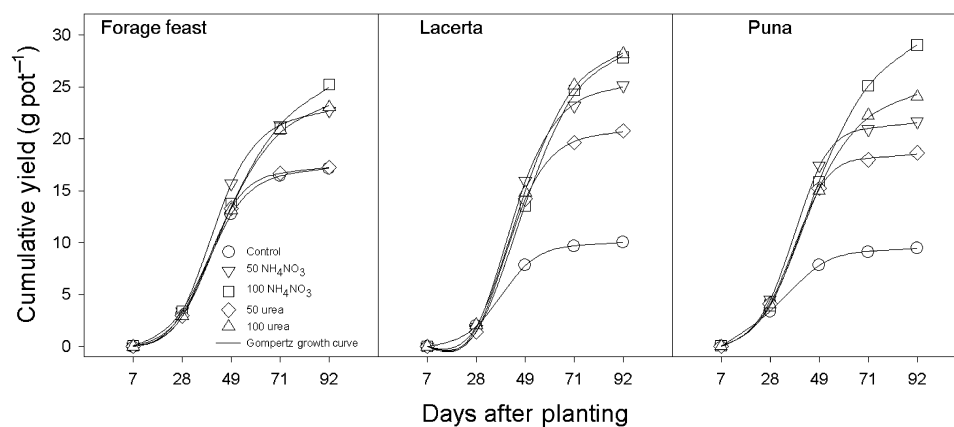


Fig. 1: Cumulative leaf dry-matter yield as a function of N rate, source and chicory cultivar. Fitted lines are calculated from the Gompertz growth model

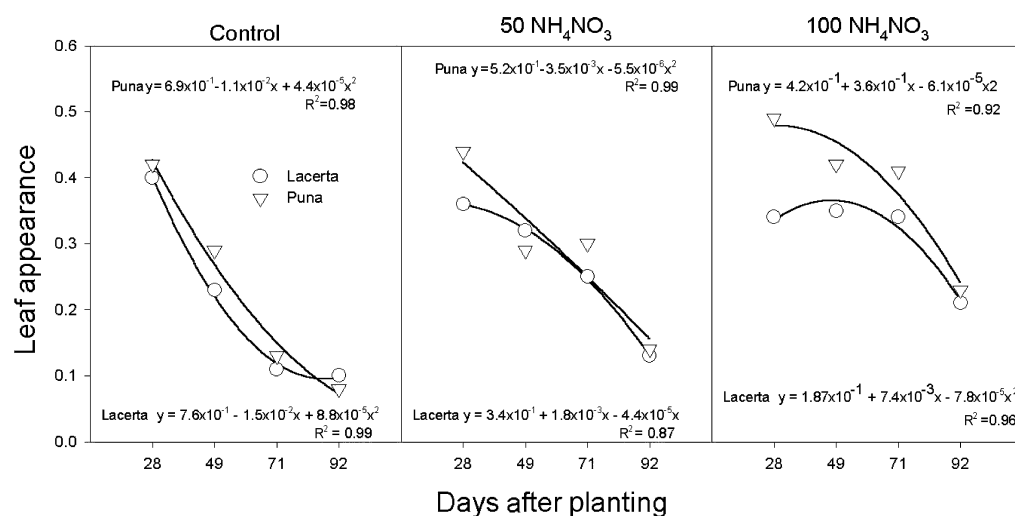


Fig. 2: Leaf appearance rate (leaves day<sup>-1</sup>) of chicory. Response illustrated with lines generated from the regression equation

Nitrogen (NH<sub>4</sub>NO<sub>3</sub>) increased leaf appearance in Lacerta and Grasslands Puna with the rate being greater at 100 N than at 50 N (Fig. 2). The results suggest that N could improve the likelihood of chicory establishment where leaf number is considered a criterion for success (Sanderson and Elwinger 2000). Under field conditions, plant density as well as leaf appearance should be taken into consideration for stand persistence when high rates of N are applied (see Belesky and Ruckle 2000). The leaf appearance rate of Lacerta, prior to N application averaged 0.21 leaves plant<sup>-1</sup> day<sup>-1</sup> or about 10 leaves in a 50-day growth interval. Sanderson and Elwinger (2000) found that six to eight leaves appeared in a 50-day interval without additions of N, regardless of whether plants were grown in field or controlled environment conditions.

Appearance rates for the first three harvests were greater than those at the last harvest when N

was provided, suggesting a change in resource allocation occurring 6–7 weeks after emergence (Fig. 2). The change is linked to N nutrition (considered in subsequent sections of this paper). Consequently, our observations are consistent with the phases of chicory development described by Ameziame et al. (1997) where structural growth occurs for the first 1.5–2 months, after which the chicory plant enters a maturation phase characterized by fructan accumulation in the taproot.

### Growth rates

Photosynthetic activity of leaves is related to N content (Robson and Parsons 1978) and leaf age. Synchronizing N application with the needs and assimilative capabilities of the plant could optimize NUE. This requires an understanding of plant growth rate and N content. Seedling growth depends on leaf formation and expansion, with

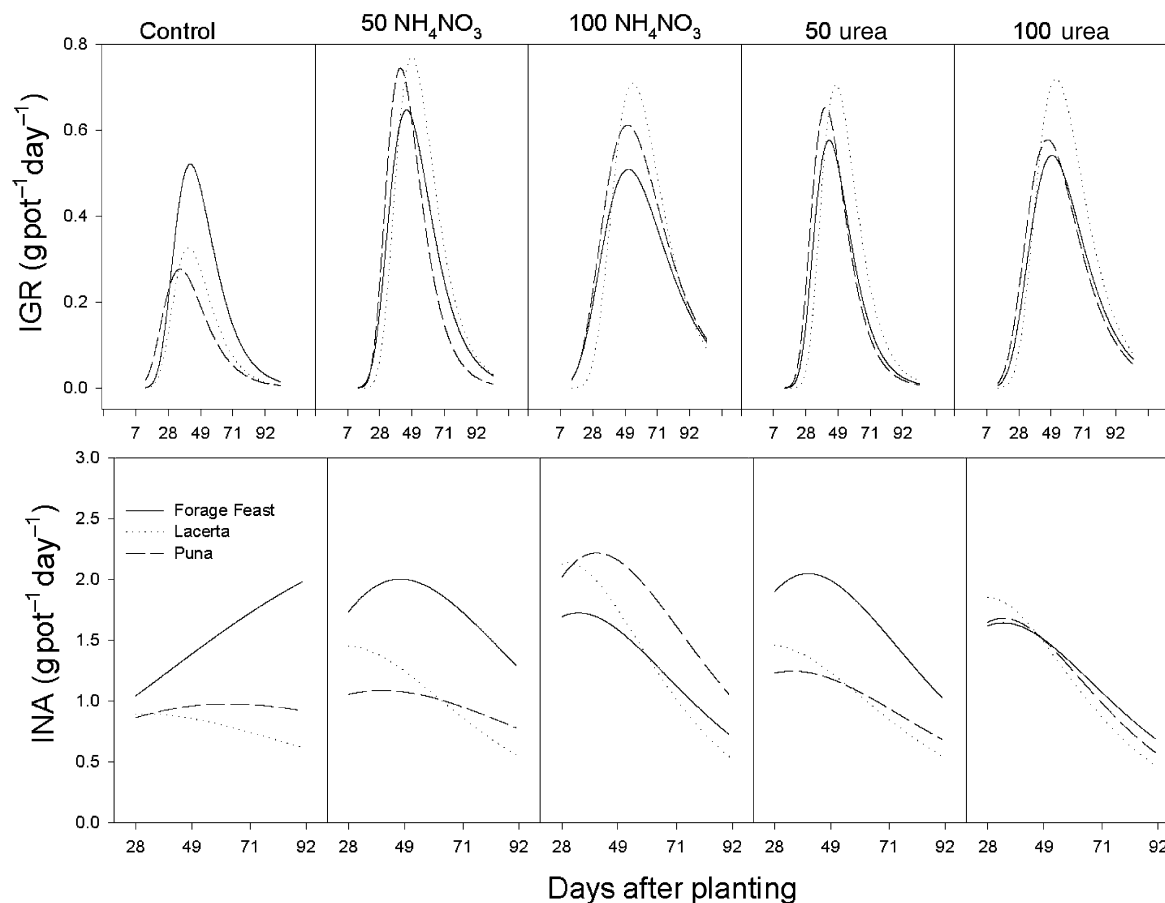


Fig. 3: Instantaneous growth rates (IGR) and instantaneous nitrogen accumulation rate (INA) of chicory cultivars in response to N rate and source for derived from the Gompertz growth model of cumulative leaf yield. Inflection points and coefficients of determination for regression models of IGR and INA are presented in Table 4

growth rate a useful comparative index of the ecological behaviour and plant response to specific conditions.

We modelled growth rate as IGR of shoots of forage chicory, and found that IGR differed with N supply and cultivar (Fig. 3). Maximum production was achieved later in the growth interval with 100 N (see inflection points in Table 4, suggesting that the interval of vegetative growth could be extended with application of N. The maximum IGR of Grasslands Puna and Lacerta plants treated with 100 N was three times that of control plants, whereas Forage Feast rates were similar among treatments (Fig. 3).

### Nitrogen

Cumulative leaf N yield of whole plants increased with increased exogenous N relative to 0 N controls, irrespective of cultivar, and was greater in Forage Feast than either Lacerta or Grasslands

Puna, regardless of treatment (Table 5). Simply presenting N concentration masks some of the response of chicory to exogenous N application. We consider other means of expressing N response in terms of partitioning among plant parts, modelled N accumulation and NUE.

Nitrogen as a component of growth is included in models associating N in plant tissue with DM accumulation in undisturbed canopies (Greenwood et al. 1990). In general, the minimum N concentration needed for optimal growth declined as DM increased, irrespective of species within functional groups (e.g. C3 grasses, forbs, etc.). We modelled N accumulation as a function of DM and N concentration to gain insight into N management for chicory herbage production. The inflection point (Table 4) derived from the model of INA (Fig. 3) indicates when rate of N accumulation in shoots is at a maximum and suggests a point where additional N might be warranted to sustain productivity (Greenwood et al. 1990).

Table 4: Inflection point (days after planting) and coefficient of determination ( $R^2$ ) of nonlinear regression models for the influence of N rate (0, 50 or 100 mg N kg<sup>-1</sup> soil) and source (ammonium nitrate, AN or urea, UN) on dry-matter (DM) accumulation (g pot<sup>-1</sup> day<sup>-1</sup>) and N accumulation (g pot<sup>-1</sup> day<sup>-1</sup>) of Forage Feast, Lacerta and Grasslands Puna forage chicory (see Fig. 3)

Treatment	DM accumulation		N accumulation	
	Inflection point†	$R^2$	Inflection point	$R^2$
<b>Forage Feast</b>				
0 N	36	0.72	156	0.97
50 AN	38	0.82	48	0.99
100 AN	43	0.93	35	0.98
50 UN	35	0.97	42	0.98
100 UN	42	0.92	35	0.98
<b>Lacerta</b>				
0 N	35	0.79	32	0.99
50 AN	41	0.86	28	0.97
100 AN	46	0.81	31	0.99
50 UN	40	0.92	27	0.99
100 UN	44	0.95	29	0.99
<b>Grasslands Puna</b>				
0 N	29	0.66	64	0.96
50 AN	34	0.86	42	0.94
100 AN	43	0.81	42	0.95
50 UN	33	0.92	36	0.93
100 UN	39	0.95	35	0.95

†Estimate of  $dy^2/dx^2 = 0$  for the first derivative of the Gompertz growth equation.

Table 5: Cumulative leaf N yield (g N 100 g<sup>-1</sup> DM) of Forage Feast, Lacerta and Grasslands Puna chicory as influenced by N rate (0, 50 or 100 mg N kg<sup>-1</sup> soil) and source (ammonium nitrate, AN or urea, UN)

	Forage Feast	Lacerta	Grasslands Puna
0 N	11.69 ± 0.54†	10.26 ± 0.86	9.75 ± 0.52
50 AN	14.29 ± 0.42	11.61 ± 0.85	10.74 ± 0.59
100 AN	15.95 ± 0.32	14.27 ± 0.72	14.98 ± 0.59
50 UN	12.79 ± 0.54	12.18 ± 0.83	12.13 ± 0.49
100 UN	15.78 ± 0.49	12.50 ± 0.80	12.40 ± 0.54

Values are mean ± S.E. of the mean.

†Each value is the mean of five replicates and represents cumulative N yield of four harvests of leaf collected from repeatedly clipped plants at 63 days after staging.

Increased exogenous N increased maximum INA in Grasslands Puna and Lacerta, but not Forage Feast (Fig. 3). The INA of Forage Feast was greater than it was for either Grasslands Puna or Lacerta at 0 N, suggesting that Forage Feast grew

Table 6: Whole plant nitrogen use efficiency of Forage Feast, Lacerta and Grasslands Puna chicory influenced by N rate (0, 50 or 100 mg N kg<sup>-1</sup> soil) and source (ammonium nitrate, AN or urea, UN)

	Forage Feast	Lacerta	Grasslands Puna
0 N	60 ± 1.42	72 ± 1.72	73 ± 4.15
50 AN	37 ± 0.99	56 ± 0.59	57 ± 2.68
50 UN	50 ± 1.20	55 ± 0.35	47 ± 2.19
100 AN	34 ± 0.36	40 ± 0.63	35 ± 1.15
100 UN	37 ± 1.34	49 ± 0.39	51 ± 3.64

Values are mean ± S.E. of the mean.

well without exogenous N. Forage Feast produced twice as much DM as either Grasslands Puna or Lacerta at 0 N (Fig. 1). The decline in Forage Feast INA with increasing N was reflected in relatively less harvestable leaf and more root and shoot residual DM accumulation, indicating that the root is the primary photosynthate sink in Forage Feast.

Aerts (1989) noted that as supplied N increased, NUE decreased. Nitrogen and cultivar interacted to influence whole plant NUE (Table 1). The NUE was greatest when no exogenous N was supplied and decreased as supplied N increased, for each cultivar (Table 6). Forage Feast had the lowest whole plant NUE of any of the chicory cultivars and NUE of Lacerta and Grasslands Puna were similar. Plants with high N retention, achieved by long-lived leaves or photosynthate allocation to roots or structures not subject to frequent removal or loss, leads to a higher NUE and possible adaptation to low nutrient or extensively managed situations. By repeated clipping (simulated brief phyllochron) and application of exogenous N, we caused responses characteristic of fast-growing plants. Forage Feast had the greatest allocation of resources to root suggesting that photosynthate partitioning to roots could be associated with optimal growth at limited nutrient supply (see Mooney and Winner 1991). Forage Feast appears to behave as a slow-growing plant as described by Chapin (1991) in that secondary metabolite production is elevated and plants are less palatable to domestic and feral grazers than either Puna or Lacerta (Foster et al. 2001, 2002).

### Nitrate concentrations

Nitrate concentrations were influenced by N rate and source, cultivar and harvest date (Tables 1 & 7) and were greatest in very young chicory plants (first sampled 28 days after planting) (Fig. 4). Concen-

Table 7: Regression equations for energy : protein ratio of chicory herbage as a function of cultivar (Forage Feast, Lacerta and Grasslands Puna) and N rate (0, 50 or 100 mg N kg<sup>-1</sup> soil) and source (ammonium nitrate, AN or urea, UN) (see Fig. 5)

	Regression equations	R <sup>2</sup>
<b>Forage Feast</b>		
0 N	$y = 3.05 \times 10^{-2} (x) - 2.55 \times 10^{-4} (x^2) - 5.01 \times 10^{-1}$	0.80
50 AN	$y = 2.65 \times 10^{-2} (x) - 2.18 \times 10^{-4} (x^2) - 4.37 \times 10^{-1}$	0.44
100 AN	$y = 1.13 \times 10^{-2} (x) - 9.35 \times 10^{-5} (x^2) - 1.08 \times 10^{-1}$	0.38
50 UN	$y = 2.39 \times 10^{-2} (x) - 1.85 \times 10^{-4} (x^2) - 3.78 \times 10^{-1}$	0.49
100 UN	$y = 1.82 \times 10^{-2} (x) - 1.29 \times 10^{-4} (x^2) - 3.34 \times 10^{-1}$	0.50
<b>Lacerta</b>		
0 N	$y = 6.48 \times 10^{-2} (x) - 5.15 \times 10^{-4} (x^2) - 1.23$	0.69
50 AN	$y = 6.98 \times 10^{-2} (x) - 5.29 \times 10^{-4} (x^2) - 1.47$	0.89
100 AN	$y = 4.38 \times 10^{-2} (x) - 3.14 \times 10^{-4} (x^2) - 9.12 \times 10^{-1}$	0.88
50 UN	$y = 5.02 \times 10^{-2} (x) - 3.85 \times 10^{-4} (x^2) - 9.63 \times 10^{-1}$	0.68
100 UN	$y = 5.44 \times 10^{-2} (x) - 3.77 \times 10^{-4} (x^2) - 1.15$	0.85
<b>Grasslands Puna</b>		
0 N	$y = 4.19 \times 10^{-2} (x) - 3.36 \times 10^{-4} (x^2) - 7.62$	0.54
50 AN	$y = 7.19 \times 10^{-2} (x) - 5.82 \times 10^{-4} (x^2) - 1.41$	0.78
100 AN	$y = 1.48 \times 10^{-2} (x) - 7.86 \times 10^{-5} (x^2) - 2.64 \times 10^{-1}$	0.64
50 UN	$y = 3.48 \times 10^{-2} (x) - 2.84 \times 10^{-4} (x^2) - 5.55 \times 10^{-1}$	0.64
100 UN	$y = 3.69 \times 10^{-2} (x) - 2.82 \times 10^{-4} (x^2) - 6.89 \times 10^{-1}$	0.68

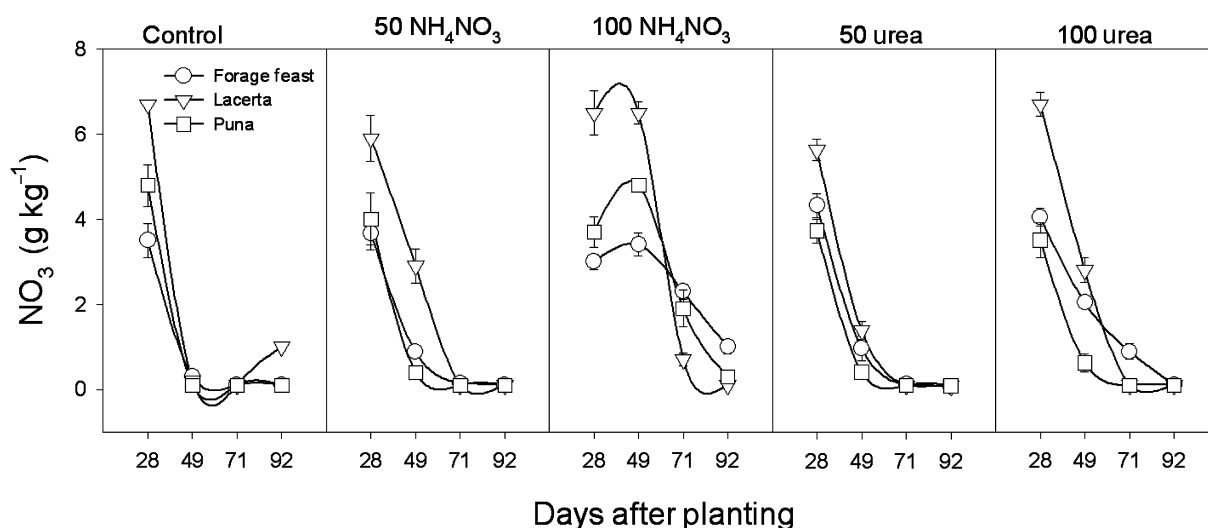


Fig. 4: Concentrations of NO<sub>3</sub> in herbage (leaves) of Grasslands Puna, Forage Feast and Lacerta chicory harvested four times as a function of N source and rate. Each point is the mean  $\pm$  S.E. of the mean of three replicates

trations declined rapidly thereafter, when plants received 0 or 50 N. Plants receiving 100 N as NH<sub>4</sub>NO<sub>3</sub> maintained elevated NO<sub>3</sub> concentrations for up to 49 days after planting. Lacerta contained the most NO<sub>3</sub>, and Forage Feast the least, suggesting rapid assimilation of N in Forage Feast. High NO<sub>3</sub> concentrations agree with previous observations of high NO<sub>3</sub> concentrations in Grasslands Puna grown under glasshouse conditions (Neel et al. 2002). The decline in NO<sub>3</sub> coincides with a shift in development from leaf or vegetative

growth to storage, as taproots begin to act as major sinks, about 1.5–2 months after planting (Ameziane et al. 1995, Richard-Molard et al. 1999). Early accumulation and gradual decline in NO<sub>3</sub> observed for Forage Feast, Lacerta and Grasslands Puna grown in glasshouse agrees with observations on field-grown Grasslands Puna (Belesky and Ruckle 2000). Repeated defoliation altered shoot : root DM allocation, but did not appear to cause an increase in NO<sub>3</sub> as suggested by Vuylsteker et al. (1997).



### Energy : protein ratio

The potential of chicory as a forage resource depends on its contribution to the nutritive value of available herbage, as well as the ability to produce DM and persist in the sward. The ratio of readily available energy (represented by non-structural carbohydrate and does not include digestible fibre) to protein provides some idea of the efficiency of chicory use by ruminant livestock. The energy : protein ratio ranged from 0.1 to about 1.0 and was influenced by N, cultivar and harvest date and interactions with harvest date (Table 1).

Forage Feast had the lowest ratio and Lacerta the greatest (Fig. 5). Grasslands Puna was, in general, intermediate relative to the other cultivars. The general quadratic response of the ratio is a function of insufficient TNC. The declines in herbage TNC coincide with increased TNC in taproot later in the growth interval (Fig. 6) corresponding to observations reported by Ameziane et al. (1997). Energy : protein ratios are suboptimal in terms of dietary requirements for grazing livestock (e.g. beef cattle; National Research Council 1996). Ratios indicate that chicory herbage is a protein-rich,

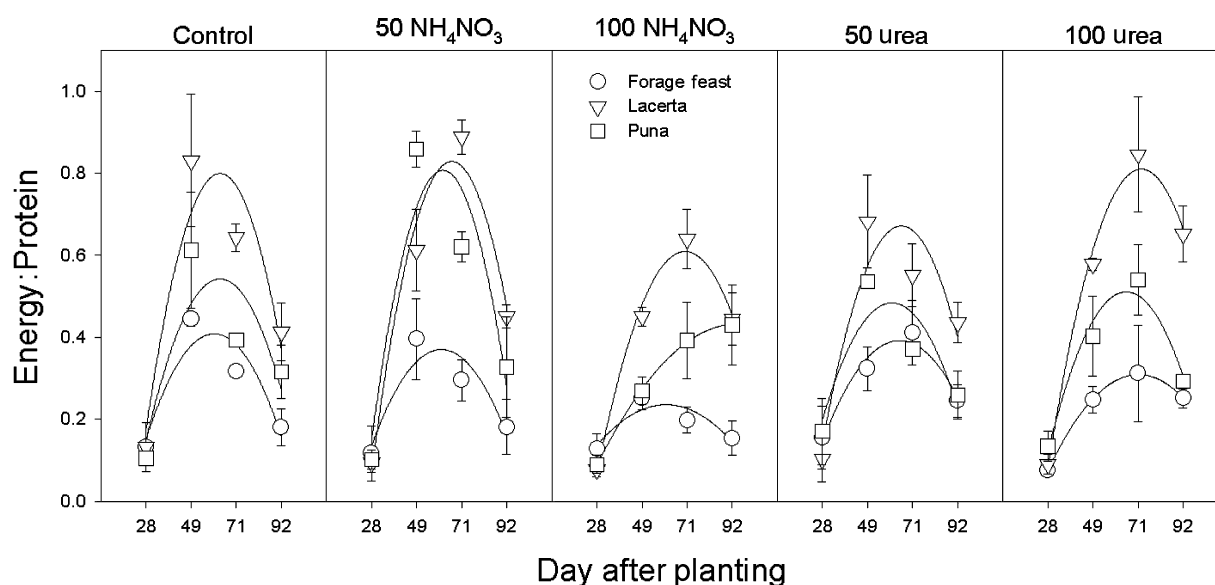


Fig. 5: Energy (total non-structural carbohydrate) : protein ratio in herbage (leaves) of Forage Feast, Lacerta and Grasslands Puna chicory harvested four times as a function of N source and rate. Each point is the mean  $\pm$  S.E. of the mean of three replicates. Regression equations are presented in Table 7

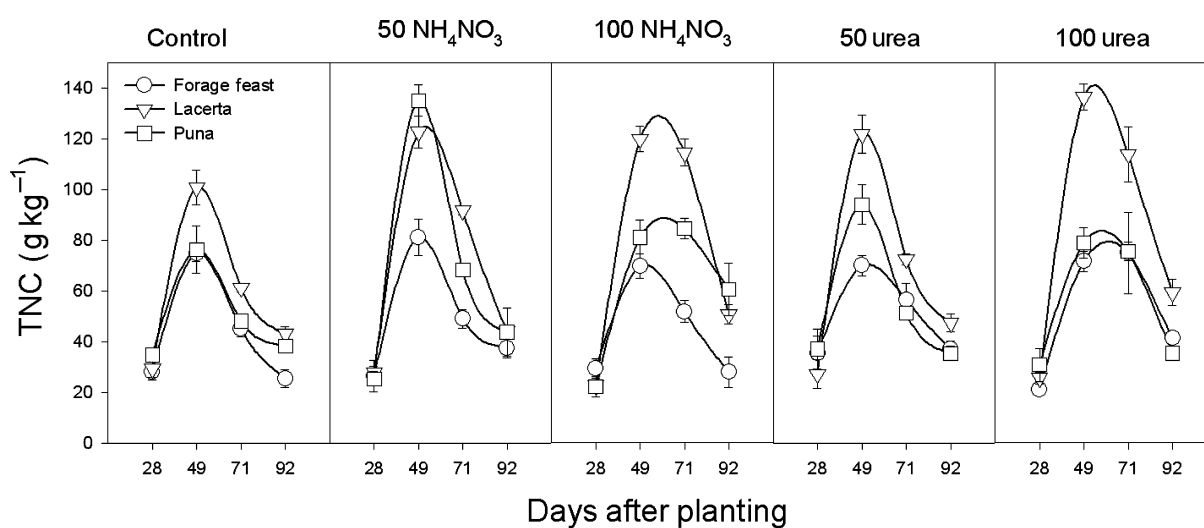


Fig. 6: Total non-structural carbohydrates in herbage (leaves) of Grasslands Puna, Forage Feast and Lacerta chicory harvested four times as a function of N source and rate. Each point is the mean  $\pm$  S.E. of the mean of three replicates

although energy-limited forage resource. Use would be optimized if it is included as part of sward mixtures where other forages meet the energy needs of livestock diets.

### Practical implications

Chicory cultivars responded differently to N amount and source in terms of DM productivity and allocation among plant parts, and N and TNC in leaves. Exogenous N as  $\text{NH}_4\text{NO}_3$  at higher amounts increased TNC in herbage of Lacerta and Grasslands Puna but not Forage Feast, and increased leaf appearance, with peak herbage production occurring later and sustained for a greater portion of the growth interval. The lowest amount of exogenous N appeared to be insufficient in terms of herbage production. Grasslands Puna reached maximum herbage growth latest and Forage Feast earliest in the growth interval, suggesting that Grasslands Puna could improve mid-season forage production in a growing season. Differences in energy : protein ratio among cultivars were a function of preferential photosynthate allocation to shoot (Lacerta) or root (Forage Feast). Grasslands Puna and Lacerta were selected for herbage production from naturalized populations of chicory in pasture, whereas Forage Feast was derived from chicory commonly used for sugar production and as such, had large taproots. Thus, chicory cultivars might have more utility than others, in particular forage production or environmental conditions (see Alloush et al. 2003 and J. G. Foster, unpublished data). For example, Forage Feast produced more herbage and greater root mass than Grasslands Puna or Lacerta with little or no exogenous N and might be useful in low input or extensively managed systems; however, TNC in Forage Feast herbage was low compared with the other cultivars and might not provide energy adequate for grazing livestock. Lacerta herbage contained the most TNC and was preferred by livestock offered free-choice, fresh-cut herbage of Grasslands Puna, Forage Feast and Lacerta (Foster et al. 2001). Forage Feast was apparently the least palatable cultivar and was found to have elevated concentrations of secondary metabolites (Foster et al. 2002) and low energy : protein ratios as shown here. Elevated secondary metabolite concentrations and low shoot : root ratios, such as those found in Forage Feast, are indicative of plants adapted to low resource situations.

### Acknowledgements

The authors thank E. C. Lester and B. A. White for excellent technical assistance with plant propagation and nitrogen analyses.

### References

- Aerts, R., 1989: Nitrogen use efficiency in relation to nitrogen availability and plant community composition. In: H. Lambers, M. L. Cambridge, H. Konings, and T. L. Pons (eds), *Causes and Consequences of Variation in Growth Rate and Productivity of Higher Plants*. pp. 285—297. SPB Acad. Publ. BV, The Hague, Netherlands.
- Alemseged, Y., D. R. Kemp, G. W. King, D. L. Michalk, and M. Goodacre, 2003: The influence of grazing management on the competitiveness, persistence and productivity of chicory (*Cichorium intybus* L.). *Aust. J. Exp. Agric.* **43**, 127—133.
- Alloush, G. A., D. P. Belesky, and W. M. Clapham, 2003: Forage chicory: a plant resource for nutrient-rich sites. *J. Agron. Crop Sci.* **189**, 96—104.
- Ameziane, R., M. A. Limami, G. Noctor, and J.-F. Morot-Gaudry, 1995: Effect of nitrate concentration during growth on carbon partitioning and sink strength in chicory. *J. Exp. Bot.* **46**, 1423—1428.
- Ameziane, R., E. Deleens, G. Noctor, J.-F. Morot-Gaudry, and M. A. Limami, 1997: Stage of development is an important determinant in the effect of nitrate on photoassimilate ( $^{13}\text{C}$ ) partitioning in chicory (*Cichorium intybus*). *J. Exp. Bot.* **48**, 25—33.
- Belesky, D., and J. M. Ruckle, 2000: Influence of nitrogen on productivity and nutritive value of forage chicory. *Agron. J.* **92**, 472—478.
- Belesky, D. P., K. E. Turner, J. M. Fedders, and J. M. Ruckle, 1999: Productivity, botanical composition, and nutritive value of forage chicory. *Agron. J.* **91**, 450—456.
- Chapin, F. S., III, 1991: Effect of multiple environmental stresses on nutrient availability and use. In: H. A. Mooney, W. E. Winner, and E. J. Pell (eds), *Response of Plants to Multiple Stresses*. pp. 67—88. Academic Press, Inc., New York.
- Clapham, W. M., J. M. Fedders, D. P. Belesky, and J. G. Foster, 2001: Developmental dynamics of forage chicory (*Cichorium intybus* L.). *Agron. J.* **93**, 443—450.
- Collins, M., and J. E. McCoy, 1997: Chicory productivity, forage quality, and response to nitrogen fertilization. *Agron. J.* **89**, 232—238.
- Consalter, A., A. Rigato, L. Clamor, and P. Giandon, 1992: Determination of nitrate in vegetables using an ion-selective electrode. *J. Fd. Comp. Anal.* **5**, 252—256.
- Denison, R. F., J. M. Fedders, and C. B. S. Tong, 1990: Amyloglucosidase hydrolysis can overestimate starch concentration of plants. *Agron. J.* **82**, 869—873.
- Draper, N. R., and H. Smith, 1981: *Applied Regression Analysis*, 2nd edn. John Wiley & Sons, New York.

- Foster, J. G., J. W. Robertson, D. P. Bligh, D. P. Belesky, and W. M. Clapham, 2001: Variations in the chemical composition of commercial cultivars of forage chicory. In: T. Terrill (ed.), Proc. Am. For. Grassl. Conf. 22–25 April. Springdale, Arkansas. AFGC. Georgetown, Texas.
- Foster, J. G., J. M. Fedders, W. M. Clapham, J. W. Robertson, D. P. Bligh, and K. E. Turner, 2002: Nutritive value and animal selection of forage chicory cultivars grown in central Appalachia. *Agron. J.* **94**, 1034–1042.
- Greenwood, D. J., G. Lemaire, G. Gosse, P. Cruz, A. Draycott, and J. J. Neeteson, 1990: Decline in percentage N of C3 and C4 crops with increasing plant mass. *Ann. Bot.* **66**, 425–436.
- Jarvis, S. C., and J. H. MacDuff, 1989: Nitrate nutrition of grasses from steady-state supplied in solution culture following nitrate deprivation and/or defoliation. I. Recovery of uptake and growth and their interactions. *J. Exp. Bot.* **40**, 965–975.
- Jung, G. A., J. A. Shaffer, G. A. Varga, and J. R. Everhart, 1996: Performance of Grasslands Puna chicory at different management levels. *Agron. J.* **88**, 104–111.
- Kunelius, H. T., and K. B. MacRae, 1999: Forage chicory persists in combination with cool-season grasses and legumes. *Can. J. Plant Sci.* **79**, 197–200.
- Latour, P., and W. Thompson, 1997: Making Business Decisions using ANOVA and Regression Techniques. SAS Inst. Inc., Cary, NC, USA.
- Li, G. D., P. D. Kemp, and J. Hodgson, 1994: Control of reproductive growth in Puna chicory by grazing management. *Proc. N. Z. Grassl. Assoc.* **56**, 213–217.
- Littell, R. C., G. A. Milliken, W. W. Stroup, and R. D. Wolfinger, 1996: SAS® Systems for Mixed Models. SAS Inst. Inc., Cary, NC, USA.
- Locascio, S. J., W. J. Wiltbank, D. D. Gul, and D. N. Maynard, 1984: Fruit and vegetable quality as affected by nitrogen nutrition. In: R. D. Hauck (ed.), Nitrogen in Crop Production. pp. 617–626. ASA, CSSA, SSSA, Madison, Wisconsin.
- Mooney, H. A., and W. E. Winner, 1991: Partitioning response of plants to stress. In: H. A. Mooney, W. E. Winner, and E. J. Pell (eds), Response of Plants to Multiple Stresses. pp. 129–141. Academic Press, Inc., New York.
- National Research Council, 1996: Nutrient Requirements for Beef Cattle, 7th revised edn. Natl. Acad. Sci. – Natl. Res. Council. Washington, DC.
- Neel, J. P. S., G. A. Alloush, D. P. Belesky, and W. M. Clapham, 2002: Influence of rhizosphere ionic strength on mineral composition, dry matter yield and nutritive value of forage chicory. *J. Agron. Crop Sci.* **188**, 398–407.
- Richard-Molard, C., S. Wuillème, C. Scheel, P. M. Gresshoff, J.-F. Morot-Gaudry, and A. M. Limami, 1999: Nitrogen-induced changes in morphological development and bacterial susceptibility of Belgian endive (*Cichorium intybus* L.) are genotype-dependent. *Planta* **209**, 389–398.
- Robson, M. J., and A. J. Parsons, 1978: Nitrogen deficiency in small closed communities of S24 ryegrass. 1. Photosynthesis, respiration, dry matter production and partition. *Ann. Bot.* **42**, 1185–1197.
- Sanderson, M. A., and G. F. Elwinger, 2000: Seedling development of chicory and plantain. *Agron. J.* **92**, 69–74.
- Santamaria, P., A. Elia, G. Papa, and F. Serio, 1998: Nitrate and ammonium nutrition in chicory and rocket salad plants. *J. Plant Nutr.* **21**, 1779–1789.
- Smith, D., 1981: Removing and analyzing total non-structural carbohydrates from plant tissues. Research Report, College of Agricultural and Life Sciences, University of Wisconsin. R2107.
- Vuylsteker, C., B. Huss, and S. Rambour, 1997: Nitrate reductase activity in chicory roots following excision. *J. Exp. Bot.* **48**, 59–65.